Executive Summary

Denitrogenation protocols (removing nitrogen from the body) shall be employed to minimize the formulation of gas emboli (bubbles) forming during an EVA. Moving from a higher pressure to a lower pressure too quickly and without adequate denitrogenation can cause bubbles to form in the body. DCS should also be minimized during off-nominal events such as cabin depressurization. If a suit (LEA-Launch, Entry, Abort) is implemented during a cabin depressurization event, it requires sufficient pressure relative to the initial cabin pressure to be effective. DCS mitigation protocols are implemented through the combination of habitat and EVA suit pressure and breathing gas procedures to achieve nominal mission operations.

Relevant Standards

NASA-STD-3001 Volume 1, Rev B
[V1 3003] In-Mission Preventive Health Care
[V1 3004] In-Mission Medical Care

NASA-STD-3001 Volume 2, Rev C
[V2 6002] Inert Diluent Gas
[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure
[V2 6007] Rate of Pressure Change
[V2 6008] Decompression Sickness (DCS) Risk Identification
[V2 6009] Decompression Sickness Treatment Capability
[V2 9053] Protective Equipment
[V2 11032] LEA Suited Decompression Sickness Prevention Capability
[V2 11100] Pressure Suits for Protection from Cabin Depressurization

Crewmembers completing prebreathe protocol prior to EVA

Background

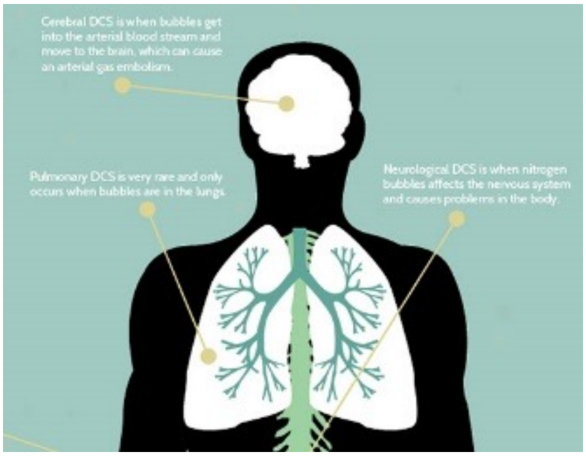
Decompression Sickness Mitigation/Prevention/Treatment

- DCS is a major concern in spaceflight, as well as terrestrially, due to the negative consequences during and after DCS occurrence.
- DCS is the result of nitrogen bubbles (or other gas emboli) causing damage to tissue.
    - Gas emboli can be classified as venous gas emboli (VGE) or arterial gas emboli (AGE).
    - VGE are removed from circulation by the lungs, whereas AGE compromise tissue oxygenation and therefore are more serious.
    - Conkin, et al (3) describes DCS as, "[When an] astronaut travels to a hypobaric environment, the amount of inert gas in excess of what can be held in solution at the new lower pressure has the potential to come out of solution to form gas spaces that can displace or otherwise damage tissues."
- DCS is typically mitigated with prebreathe protocols – denitrogenation of the body with oxygen.
- The risk of DCS is shown to increase during ambulation and periods of increased lower body activity on Earth.

Risks of Decompression Sickness

- **Type I:** joint pain, single extremity tingling or numbness, and mild skin symptoms.
- **Type II:** central nervous system or cardiovascular symptoms (potentially fatal). Symptoms can range from muscle weakness, confusion, impaired balance, and stroke.

Type I: Joint Pain



Type II: Gas bubbles in pulmonary/lungs (chokes), cerebral/brain, neurological

The goal is to limit DCS risk to within acceptable levels through validated prebreathe protocols.

Reference Data

Decompression Sickness Mitigation/Prevention/Treatment

Past NASA Decompression Protocols for Prevention of DCS

NASA has never experienced a Type II event in spaceflight

In-Suit 4-Hour Prebreathe

Astronaut breathes 100% O2 in the spacesuit at 14.7 psia for 4 hours.

Campout Protocol

Significantly reduces the required in-suit prebreathe duration by having EVA crewmembers “camp out” in the ISS airlock at 10.2 psia, 26.5% O2 during the night prior to their EVA. For various operational reasons, the time at 10.2 psia is limited to 8 hours and 40 minutes.

Exercise Protocol

Intense, short exercise regimen at 14.7 psia while breathing 100% O2 combined with in-suit prebreathe at 10.2 psia.

In-Suit Light Exercise (ISLE) Protocol

A longer period of mild exercise in the EMU. The ISLE protocol shares many steps with the exercise prebreathe protocol but differs in that 40 minutes are spent breathing 100% O2 by mask followed by a 20-minute depressurization to 10.2 psia.

Notes:

- DCS risk is significantly increased by ambulation and physical activity during altitude exposure, meaning ISS microgravity prebreathe protocols are not effective for planetary EVA.
- Apollo used a 100% O2 cabin environment which eliminated DCS risk during EVA.

Past prebreathe protocols were between 3-5 hours. Utilizing a lower cabin pressure/higher oxygen concentration such as 8.2 psia with 34% O2 can minimize the time to denitrogenate the body, which saves time and consumables.

The following pages detail a comparison of prebreathe durations and atmosphere compositions.

Application Notes

Decompression Sickness Mitigation

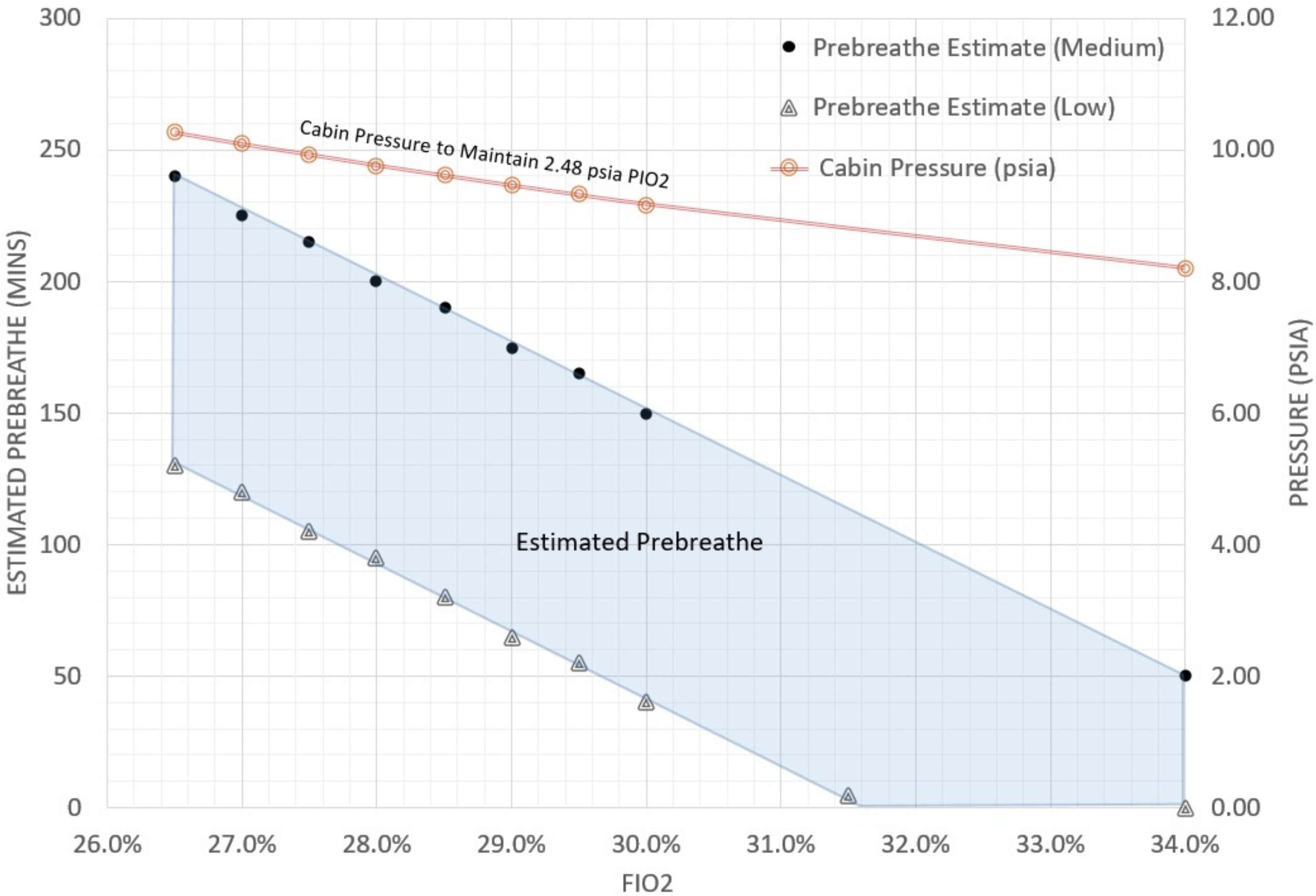
Design Guidance

- The key to preventing DCS is to denitrogenate the body by breathing higher levels of oxygen and optimizing the pressures of the cabin and the suit.
- DCS requires cross discipline activities to provide effective mitigation:
  - Habitat pressure and oxygen concentration.
  - Suit Pressure and oxygen concentration.
- Duration of prebreathe is determined by the pressure, percent oxygen, and nitrogen of the atmosphere. See the graph on the following page for prebreathe estimates based on 2.48 psia P_IO_2 and 4.3 psia space suit operating pressure.
- Ineffective designs can consume larger amounts of oxygen and take more time prior to initiating an EVA (from many hours to minutes).
- Treatment is performed using the total pressures from the vehicle and suit atmospheres.
  - When DCS symptoms occur, the suit and cabin pressure may be combined to resolve symptoms or the cabin pressure needs to be increased . A minimum of 16.4 psia is recommended but is scenario dependent.
- Type II DCS prevention during a cabin depressurization may require the use of a suit (e.g. LEA suit).
  - The suit should be able to reach sufficient pressure to lessen DCS symptoms, if they cannot be prevented altogether.
  - An LEA suit pressure of 5.8 psia has been shown to reduce the risk of Type II DCS to <15% for a rapid depressurization. For more information, reference the Decompression Events and LEA Suits Technical Brief.

Reference Data

Prebreathe Estimates vs. O_2 concentration & Cabin Pressure

The graph below is an estimate of pre breathe times vs. oxygen levels and cabin pressure at a hypoxic limit of 2.48 P_IO_2 for EVAs with a suit pressure of 4.3 psia. At 8.2 psia and 34% O2 the prebreathe would be minimal. These values need to be validated prior to implementation.



Prebreathe Estimates based on 2.48 psia P_IO_2 and 4.3 psia space suit operating pressure

Note: The Apollo program used a 5.0 psia 100% O_2 cabin atmosphere, thereby eliminating DCS risk and the need for prebreathe.

Back-Up

Major Changes Between Revisions

Rev A → Rev B

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Original → Rev A

Slide 1

- Minor update to Executive Summary

Slide 2

- Updated Background information

Slide 3

- Past Protocols updated with additional information
- Additional notes added
- Table and references removed and updated on additional slides
- Application Notes slide removed completely

Slide 5

- Added slide to capture new pre-breathe table

Slide 7

- Added slide detailing Referenced Standards

Slide 8

- Added slide with additional references

Referenced Standards

NASA-STD-3001 Volume 1 Revision B

[V1 3003] In-Mission Preventive Health Care All programs shall provide training, in-mission capabilities, and resources to monitor physiological and psychosocial well-being and enable delivery of in-mission preventive health care, based on epidemiological evidence-based probabilistic risk assessment (PRA) that takes into account the needs and limitations of each specific design reference mission (DRM), and parameters such as mission duration, expected return time to Earth, mission route and destination, expected radiation profile, concept of operations, and more. The term "in-mission" covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In-mission preventive care includes, but is not limited to: (see NASA-STD-3001, Volume 1 Rev B for full standard).

[V1 3004] In-Mission Medical Care All programs shall provide training, in-mission medical capabilities, and resources to diagnose and treat potential medical conditions based on epidemiological evidence-based PRA, clinical practice guidelines and expertise, historical review, mission parameters, and vehicle-derived limitations. These analyses should consider the needs and limitations of each specific DRM and vehicles. The term "in-mission" covers all phases of the mission, from launch, through landing on a planetary body and all surface activities entailed, up to landing back on Earth. In-mission capabilities (including hardware and software), resources (including consumables), and training to enable in-mission medical care, are to include, but are not limited to: (see NASA-STD-3001, Volume 1 Rev B for full standard).

NASa-STD-3001 Volume 2 Revision C

[V2 6002] Inert Diluent Gas Cabin atmospheric composition shall contain at least 30% diluent gas (assuming balance oxygen).

[V2 6006] Total Pressure Tolerance Range for Indefinite Crew Exposure The system shall maintain the pressure to which the crew is exposed to between 26.2 kPa < pressure ≤ 103 kPa (3.8 psia < pressure ≤ 14.9 psia) for indefinite human exposure without measurable impairments to health or performance.

[V2 6007] Rate of Pressure Change For pressure changes >1.0 psi, the rate of change of total internal vehicle pressure shall not exceed 13.5 psi/min.

[V2 6008] Decompression Sickness (DCS) Risk Identification Each program shall define mission unique DCS mitigation strategies to achieve the level of acceptable risk of DCS as defined below within 95% statistical confidence:

a. DCS ≤ 15% (includes Type I or isolated cutis marmorata).
b. Grade IV venous gas emboli (VGE) ≤ 20%.
c. Prevent Type II DCS.

[V2 6009] Decompression Sickness Treatment Capability The system shall provide DCS treatment capability.

[V2 9053] Protective Equipment Protective equipment shall be provided to protect the crew from expected hazards.

[V2 11032] LEA Suited Decompression Sickness Prevention Capability LEA spacesuits shall be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

[V2 11100] Pressure Suits for Protection from Cabin Depressurization The system shall provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization (such as in mission dockings, operations during periods of high incidence of Micrometeoroids and Orbital Debris (MMOD) or complex vehicle maneuvers).

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